# TECHNOLOGICAL PROXIMITY AND THE INTENSITY OF COLLABORATION ALONG THE INNOVATION FUNNEL: DIRECT AND JOINT EFFECTS ON INNOVATIVE PERFORMANCE

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## ABSTRACT

This work aims to advance the understanding regarding the profiting of collaborative innovation practices, focusing particularly on how the intensity of collaboration along the innovation process and the relatedness between the partners' technological bases affect the outcomes of such process, in terms of efficiency and generation of technological innovations. Drawing on the results from causal models and the estimation of average marginal effects, this research analyses the direct and joint effect of technological proximity and intensity of collaboration in the early and late phases of the process. The findings suggest that there is a positive unconditional relationship between the aforementioned aspects and innovative performance, and that the joint effects diverge depending on the stage of the process; i.e., while in the early phase, collaborating intensely with close partners seems to be advisable, this circumstance proves to be problematic in the late phase of the innovation process.

## 1. INTRODUCTION

Collaboration across organizational boundaries for R&D&I purposes has become commonplace in the last decades (Powell and Grodal, 2005), a fact that has been widely acknowledged in management literature. In fact, scholars have recognized for a long time now that companies typically innovate in collaboration and interdependence with various agents (other businesses, customers, suppliers, governments, universities, etc.), thus pointing out the systemic nature of innovation processes (e.g., Dyer and Singh, 1998; Nooteboom, 1999). Accordingly, literature has extensively emphasized the importance of R&D inter-organizational collaborations, in order to succeed in the implementation of innovation strategies (e.g., Arora and Gambardella, 1994; Veugelers and Cassiman, 1999), and it can be stated that there is a general agreement on considering that collaborative innovation practices have a positive effect on innovative performance (Un et al., 2010).

In line with the logics inherent to combinative capabilities theories (Kogut and Zander, 1992), prominent contributions in the field of management research address the importance of complementing assets and activities (e.g., Stieglitz and Heine, 2007) and of combining internal and external capabilities to innovate. Indeed, a firm's innovativeness is constrained by its existing capabilities (Teece, 1986); thus, complementing internal capabilities with those that can be obtained through external sources plays a crucial role in firms' innovative performance.

The analysis of the occurrence of complementarities when pursuing knowledge and technology sharing in collaborative R&D activities has benefited from the proximity approach[1], which seeks to shed light on the relative position of economic agents with respect to each other (Boschma, 2005; Cassi and Plunket, 2015) and how these relatedness (or distance) informs the configurations of partnerships and networks and influences the outcomes of such ventures. Regarding this last aspect, it has been widely acknowledged that proximity between R&D collaborators facilitates knowledge sharing and innovation, as it mitigates the negative effects of

[1] This approach was brought to the front line by the special issue of *Regional Studies* on 'The Role of Proximity in Interaction and Performance' (2005).

uncertainty and coordination problems (Boschma, 2005) and guarantees considerable levels of understanding needed in complex and high-risk processes (Menzel, 2008). However, literature has also accounted for the negative effects of proximity, which might imply a lock-in problem, thus hindering flexibility and creativity and leading to negative results in innovativeness (Boschma, 2005). This ‘proximity paradox’, as coined by Boschma and Frenken (2010), has been tested by several studies (e.g., Broekel and Boschma, 2011; Huber, 2012; Cassi and Plunket, 2015), leading to inconclusive results and thus calling for further research on the topic (Balland et al., 2015; Bouba-Olga et al., 2015).

On another note, when tackling the concept of proximity, there is a strong consensus that the phenomenon exceeds mere spatial considerations, and that non-geographical factors have to be taken into account in order to fully account for the effects of proximity on innovativeness (Boschma, 2005; Mattes, 2012; Bouba-Olga et al., 2015).

Despite the interest shown by academics on the phenomenon of proximity and it being regarded as essential to explain innovation outcomes, there is still limited understanding, on the one hand, on how non-geographical dimensions of proximity affect innovative performance, and on the other, on how the aforementioned ‘proximity paradox’ plays out according to empirical evidence (Huber, 2012; Bouba-Olga et al., 2015). Accordingly, this work focuses on the relatedness between the focal firm and its partners, understood as closeness in terms of knowledge bases (technological proximity), taking into account that the ‘proximity paradox’ has been found to be particularly relevant for technological (or cognitive) proximity (Broekel and Boschma, 2011; Huber, 2012).

Furthermore, this research aims to shed light into the intersection of this dimension with another prominent aspect determining the outcomes of collaborative innovation practices, i.e., the intensity of the partnership along the process. In this sense, the benefits of developing 'strong ties' with R&D partners has been widely acknowledged (i.e., Hansen, 1999; Capaldo, 2007), as intensive cooperation permits the development of complex and iterative tasks (Hsieh and Tidd, 2002) and improves the effectiveness in the transfer of complex and tacit knowledge (Hagedoorn, 1993; Mattes, 2016). Also, when taking into account the existence of different phases in the collaborative innovation practices, literature has established that high levels of intensity in R&D partnerships are beneficial both in early stages of process (Witell et al., 2011) and in subsequent stages (Bogers and Horst, 2014).

Nevertheless, enhancing the transfer of complex knowledge might have different implications in earlier and later phases of the collaborative innovation funnel depending on the degree of technological relatedness between the partners' knowledge bases. Indeed, while the first stages of the process tend to be precompetitive, the later phases are characterized by a higher risk of opportunistic behavior (Lakemond et al., 2016). Thus, collaborating intensely with R&D partners in the implementation stages might imply drawbacks linked to appropriability problems and the risk of involuntary leakage of critical knowledge, which turn increases in the face of overlapping technological bases (Boschma, 2005).

Therefore, the present study aims to advance the understanding of how innovative performance, measured in terms of efficiency and generation of technological innovation outputs, might be affected by complementarities between technological proximity and the intensity of collaboration when engaging in R&D partnerships along the innovation funnel.

The understanding of the aforementioned phenomenon, enlightened by the results obtained in this work, will be of great interest for practitioners and policy makers alike, as it provides clarity for decision making regarding relevant aspects of collaborative innovation practices; particularly, the search for and selection of optimal partners. In general terms, the evidence found here suggests seeking for collaborating intensely along the whole process with partners with related technological bases p. Results also call for awareness of the potential drawbacks of intense collaborations with close partners in the late phases of the process, thus hinting towards the convenience of developing protection mechanisms.

Also, this work presents contributes to the literature on innovation management, providing interesting insights that challenge the notion of 'proximity paradox' and set out further questions that might be worth considering for future research.

The structure of the rest of the paper offers a section devoted to the revision of extant literature, the proposal of hypothesis and the configuration of the theoretical framework for the research, followed by a section explaining the methodology. Results and their discussion will be presented immediately afterwards. Finally, a closing section will present the conclusions of the study.

## 2. THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

### 2.1. Technological proximity and innovative performance

Proximity literature traditionally distinguishes between two canonical dimensions; i.e., geographical and organizational, the latter a term comprehending aspects related to similarities due to being part of the same organization or to the sharing of codes and norms, and still subject to much discussion and refinement (Bouba-Olga et al., 2015). Indeed, the conceptualization and characterization of the different dimensions of proximity have been the focus of several works (e.g., Boschma, 2005; Torre and Rallet, 2005; Knoben and Oerlemans, 2006). The typologies originated from these works identify, apart from the geographical dimension, several others, such as cognitive, social, institutional or technological aspects. Accordingly, several empirical studies have taken into consideration this distinction in order to formulate and test frameworks including different types of proximity (e.g., Messeni Petruzzelli et al., 2009; Cassi and Plunket, 2015). In any case, most authors come together in pointing out that geographical proximity, while usually being essential to explain the initial connections to partner up, is not sufficient per se to enable interactive learning and innovation (Boschma, 2005; Mattes, 2012; Cassi and Plunket, 2015) and that this dimension of proximity has been probably '*overemphasized to the detriment of other proximity forms*' (Bouba-Olga et al., 2015).

Technological proximity, the dimension studied here, has been acknowledged as proximity form most closely linked to innovation (Huber, 2012). Indeed, the knowledge needed to carry out innovative activities often has a tacit and idiosyncratic nature (Boschma, 2015), and its effective transfer requires proximity in terms of the partners' technological and knowledge bases (Korbi and Chouki, 2017), while at the same time the reason to partner up for innovation purposes is to get access to alien knowledge in the first place.

The notion of technological relatedness used in this work draws on the conceptualization offered by Knoben and Oerlemans (2006). The authors define technological proximity as '*the level of overlap of the knowledge bases of two collaborating actors*', referencing Lane and Lubatkin (1998). This concept is in line with notions of cognitive proximity used by other authors. From the seminal works by Nooteboom (1999, 2003) on cognitive distance to other studies proposing categorizations for the different dimensions of proximity (e.g., Boschma, 2005), cognitive proximity has been used to address the sharing of similar knowledge bases and expertise.

Nooteboom's (1999, 2003) cognitive theory illustrates the rationale explaining the controversial effect of reaching out towards sources with knowledge and capabilities substantially distant from the focal firm's knowledge base.. According to the author, for low levels of cognitive distance, its increase has a positive effect on learning, due to the interaction of agents with different knowledge and perspectives who connect complementary resources. However, once a certain level of distance is reached, further increases imply difficulties for the mutual understanding required to seize the opportunities of diverse knowledge. The key argument of the theory is thus that '*while larger distances in cognition have a negative effect on absorptive capacity, they have a positive effect on the potential for novelty creation*' (Gilsing et al., 2008). This model has been tested in several studies (e.g., Wuyts et al., 2005; Nooteboom et al., 2007; Sampson , 2007; Gilsing et al., 2008; Nambisan, 2013).

This reasoning accurately reflects the arguments of the 'proximity paradox', coined by Boschma and Frenken (2010), and lucidly displayed through the lens of the innovation logics by

Mattes (2012) when she states that innovation requires both renewal based on heterogeneity and the integration of knowledge guaranteed by proximity.

Literature on proximity has provided abundant insight into this phenomenon. For instance, Capaldo and Messeni Petruzzeli (2014) explain that proximity, being a major determinant of innovation, enhances coordination, learning and knowledge integration, while at the same time hinders access to complementary knowledge sources. Proximity dimensions would thus exert confronting effects upon innovative performance when it comes to knowledge creation and knowledge integration. In this sense, Fitjar et al. (2016) posit that the most innovative firms are those who partner up with collaborators at medium levels of proximity for all non-geographical dimensions.

More specifically, studies focusing specifically on technological proximity usually justify its positive effect on learning and innovativeness by the implications of absorptive capacity (Cohen and Levinthal, 1990), in the sense that the capacity of firms to absorb new knowledge from external sources requires the ability to identify, interpret and exploit the new knowledge (Boschma, 2005). Interestingly, Cohen and Levinthal's construct has been refined into that of *relative* absorptive capacity (Lane and Lubatkin, 1998), addressing that firms do not have an unconditional capacity to learn from any other agents. On the contrary, the absorptive capacity of a given firm depends on the similarity existing between partners at a dyadic level. In this sense, this refined construct adjusts to the inherent logics behind the arguments explaining the beneficial effects of proximity, and it has been invoked to explain why firms should guarantee a certain closeness to the partner's cognitive base in order to facilitate the understanding and internalization of knowledge (Capaldo and Messeni Petruzzeli, 2015).

On the other hand, the postulates of the resource-based view theory can be summoned to explain the pertinence of searching for heterogeneous R&D sources. According to this perspective, whose main seminal contribution dates back to Penrose (1959), the difference in performance across firms is due to the resource heterogeneity they possess. As Kor and Mahoney (2004) explain, Penrose (1959) unravels the logic behind links among resources, capabilities and competitive advantage, concluding that new combinations of resources generate innovations and lead to value creation. In search for new combinations of resources, the logic behind partnering up with external agents for R&D purposes is precisely the objective of obtaining complementary resources and know-how (Teece, 1986). The heterogeneity in the technological and knowledge bases of the partners would thus imply a chance to access supplementary resources upon which to build innovation capabilities and obtain a sustainable competitive advantage.

Ultimately, when carrying out collaborative R&D activities, partners' knowledge bases need to be similar enough so as to recognize opportunities and seize them, but different enough so that there are contributions of complementary knowledge (Knoben and Oerlemans, 2006).

Taking all of the above into account, we propose the following hypothesis.

**Hypothesis 1**: Technological proximity exerts and inverted U-shaped effect upon innovative performance.

### 2.2. R&D partnerships along the innovation funnel: intensity of the collaboration and its interactions with technological proximity

The definition of the stages of the innovation process has been a prominent topic in the research field, from the Schumpeter's early model proposing the distinction of invention, innovation and diffusion to proposals directly tackling the use of external sources of innovation (e.g., Zahra and George, 2002; West and Bogers, 2014). Although sequential models have been criticized for being too simplistic, the practicality of dividing the process into the traditional stages of research and development -thus covering the idea generation phase and its later completion and manifestation in a technological innovation- has also been acknowledged (Knudsen, 2007).

In this sense, Lazzarotti and Manzini (2009) stated that collaborative innovation practices can be studied, among other factors, taking into account the different phases of the process open to external sources. The framework established by the authors contemplates the 'innovation funnel openness' as a prominent variable defining different modes of collaborating for R&D

purposes, and includes the following phases in which firms can partner up in order to carry out the development of new technologies, product and process innovations: idea generation, experimentation, engineering and manufacturing.

The impacts of collaborating with external agents when pursuing innovative strategies has been widely studied and there is abundant literature backing up the idea of the positive effect of opening the innovation process on performance. For instance, co-creation practices in early stages of the process have been acknowledged as beneficial for generating innovative ideas (Witell et al., 2011) and leading to successful new product developments (Lilien et al., 2012). Also, literature has addressed the benefits of partnering with external sources for prototype engineering and validation and subsequent manufacturing (e.g., Vuola and Hameri, 2006; Bogers and Horst, 2014).

Traditionally, the extent to which a firm has opened its innovation process can be assessed either by the number of external sources it reaches out to, or by the level of involvement between the R&D partners at a dyadic level -literature often referring to this aspects with the terms of breath and depth (Laursen and Salter, 2006). This work focuses on the latest, addressing the innovation funnel openness via the level of involvement between the focal firm and its partners (Berchicci, 2011), thus providing a measure of the intensity of the collaboration in the different stages of the process.

Hsieh and Tidd (2002) argued that jointly developed complex and iterative tasks, such as those characteristic of R&D partnerships, require intensive collaboration. Also, in order for complex and tacit knowledge to be transferred effectively, close or intense collaboration among the partners is needed, so that the joint efforts can be capitalized (Hagedoorn, 1993; Mattes, 2012). Precisely, the abilities to access complementary knowledge and expertise depend on tacit elements (Lundvall and Johnson, 1994), and the type of knowledge usually shared in R&D partnerships has a tacit and idiosyncratic nature (Boschma, 2005). In this sense, Hansen (1999) explained that transferring tacit and interdependent knowledge through strongly-tied partnerships is likely to be more beneficial than through weakly-tied ones. Therefore, when developing R&D

collaborative activities, obtaining and integrating effective knowledge from external sources requires building intense relationships.

Several studies provide evidence on the relationship proposed by this arguments. Results obtained by Santoro (2000) showed a positive linkage between the intensity of collaborations and tangible outcomes in industry-university collaborative ventures, thus sustaining the rationale that more intense relationships imply a deeper commitment, more resources devoted to the project and stronger personal interactions, and therefore derive in a better performance. Bechicci (2011) also offered results confirming that drawing deeply from key and preferred partners has a positive effect on innovative performance. In the same sense, Chen et al. (2011) also showed that the intensity of collaboration is a paramount factor influencing innovation performance providing evidence that firms benefit from intense and strong ties with external partners.

In light of the theory and evidence mentioned, it is straightforward to expect a positive effect of the intensity of R&D collaborations on innovative performance, and thus the following hypothesis is proposed:

**Hypothesis 2**: Intense collaboration with outside parties has a positive effect on innovative performance, both in the early and late stages of the innovation process.

As for the interaction of the intensity of collaboration with technological proximity, this work proposes that its relationship with innovative performance will be different depending on the stages of the innovation process (i.e., an earlier phase devoted to generating ideas and experimenting and a later one for engineering prototypes, validating them and manufacturing).

Indeed, the early stage of the process is arguably more dependent than the later phase on knowledge recombination and complex forms of interaction between partners (Lakemond et al., 2016). As Fleming and Sorenson (2004) point out, research on technological advance has traditionally conceptualized the invention phase as a process relying heavily on the recombination of existing knowledge in a novel manner. This implies the coordination of complex dynamics deeply ingrained in tacit communication and knowledge transfer. In this context, mutually shared knowledge bases help overcoming the difficulties arising from such situations of complex interdependencies (Srikanth and Puranam, 2011). In this sense, existing literature generally suggests that the overlapping of knowledge bases helps in dealing with the problems related to ambiguous and uncertain contexts (Ritala and Hurmelinna-Laukkanen, 2013).

Technological proximity provides a common ground that enables communication and the transfer of tacit information between partners, thus reducing the costs of coordinating such a complex process (Lakemond et al., 2016). In other words, when bringing together teams from different organizations to come up with new ways of configuring knowledge and experiment with new potential technologies, a high degree of intensity in such collaboration would benefit from the overlap of the knowledge bases of the partners, which in turn enables the effective understanding of the other's proposals and facilitates the recombination of the existing knowledge. Collaborating intensely with the technologically proximate partners in the early stage of the process would thus exert a complementary beneficial effect.

On the other hand, the early stage of the R&D collaborative process tends to be precompetitive, and is thus characterized by lower risks of opportunistic behavior of the partners, that are more likely to arise on a later phase (Lakemond et al., 2016). This risk is directly related with the appropriability problem, which '*refers to the difficulties firms face in earning the full return upon their own innovative activities*' and to the eventuality that partners might take for themselves an oversized share of the benefits of the joint project (Tomlinson, 2010); which in turn places firms in a position prone to reduce their own efforts, with the subsequent detrimental effect on the innovation outcome (Ritala Hurmelinna-Laukkanen, 2013).

While *incoming* knowledge spillovers are known to be favored by proximity and are also considered one of the main opportunities arising from collaborative innovation activities (Montoro-Sánchez et al., 2009), the risk of *involuntary* knowledge leaks spreading to the partners lead to appropriability problems (Bönte, 2008).

In this sense, Laursen and Salter (2014) acknowledge this as one of the major problems associated with using external sources for innovating. The authors refer to the existence of a 'paradox of openness', in the sense that firms pursuing to obtain knowledge from external sources must face the risk of revealing part of their own knowledge to a certain extent, which implies considerable costs and efforts in order to appropriate the benefits of the joint innovation practice.

This involuntary leakage of critical knowledge, together with the likelihood of the opportunistic behavior of the partner, is thus a prominent factor shaping the dynamics of the relationship in the late stage of the collaborative innovation process. The occurrence of such involuntary spillovers responds to a variety of causes, such as the mobility of employees, the sharing of patent information or the informal transfer of sensitive information and critical knowledge between members of the R&D teams pertaining to different organizations (Mansfield, 1985). As explained above, the transfer of complex, idiosyncratic and tacit knowledge is favored by technological proximity among partners. Therefore, involuntary knowledge leakages, which imply significant costs and could harm the potential benefits of collaborative innovation, is exacerbated when partners are similar (Ardito et al, 2018); more so when their technological bases overlap (Boschma, 2005; Boschma and Frenken; 2010).

Firms collaborating in the implementation stage of the innovative process, thus, face risks due to appropriability problems and partners' opportunistic behavior. This circumstance is aggravated by the risk of involuntary spillovers, which are in turn more likely to arise if partners are proximate in technological terms. Therefore, and even though both the intensity of collaboration and a certain degree of technological proximity are expected to enhance innovative performace, collaborating intensely with proximate partners in this late phase will prove to have joint detrimental effects, in the sense that high levels on both aspects would counterbalance the unconditional benefits of proximity and intensity..

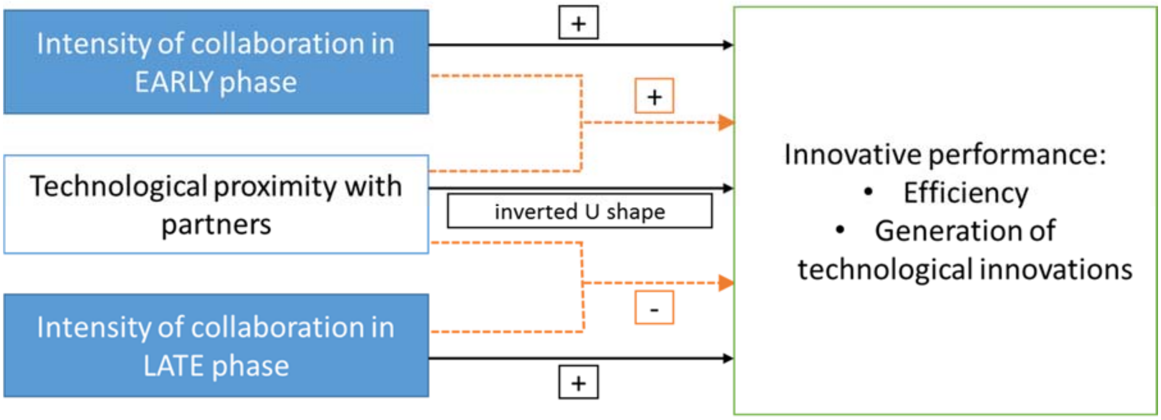
The rationale developed above regarding the effects of the interaction of the variables of collaboration intensity in different phases and technological proximity results in the following hypothesis:

**Hypothesis 3a**: The interaction of technological proximity and the intensity the collaboration in the early phase of the process has a positive effect on innovative performance.

**Hypothesis 3b**: The interaction of technological proximity and the intensity of the collaboration in the late phase of the process has a negative effect on innovative performance.

The conceptualization of the hypotheses presented are illustrated by the following figure.

**Figure 1**. Conceptualization of the theoretical framework




## 3. METHODOLOGY

The conducted research aims to estimate the direct and joint effects of technological proximity and of collaboration intensity along the innovation process on innovative performance, in terms of efficiency and generation of innovation outputs.

This quantitative analysis relies on data obtained from an international open innovation survey designed by researches from universities in Italy, Sweden, Finland and the UK and collected during 2012 and 2013, gathering information in all these four countries. Each country framed a target population of manufacturing industry firms with more than 10 employees, from which a randomized sample of 1,000 firms was selected. Questionnaires were distributed by email to the participants, who were R&D managers or similar roles familiar with collaborative innovation projects. These questionnaires cover aspects such as strategy, context, openness, relational factors (collaboration modes) and performance, and uses a 7-point Likert-type scale ranging from ‘strongly disagree’ to ‘strongly agree’ to measure the items. The total number of respondents amounted to 467 firms, from which 152 came from Italy, 176 from Sweden, 87 from Finland and 52 from the UK[2]. Regarding the industry in which the firms operate, the most representative manufacturing sectors are the following: chemical and metallic products –around 20% of the sample each–, textile products and printed items –around 10% each–, electric and electronic products, plastic and other non-metallic products, wood and paper products, and food and beverages –around 5% each. As for the size, the sample is distributed among small, medium-sized and large firms according to the following percentages: 50% for firms with 49 employees or less, 30% of the sample for firms with 50 to 249 employees, and 20% for firms with 250 employees or more.

In order to perform the analysis of the causal effects focus of this research, a linear regression model was estimated, which can be formulated as follows:

$$\begin{aligned} Inn\_perf^{*}_i = {} & \alpha + \beta_1{*}Int\_Phase1_i + \beta_2{*}Int\_Phase2_i + \beta_3{*}Tech\_prox_i + \beta_4{*}Tech\_prox^2_i \\ & + \beta_5{*}Int\_Phase1xTech\_prox_i + \beta_6{*}Int\_Phase2xTech\_prox_i + \beta_7{*}Size\_small_i + \\ & \beta_8{*}Size\_med_i + \beta_9{*}Sector\_lowtech_i + \beta_{10}{*}Innovat_i + \beta_{11}{*}Extern_i + \beta_{12}{*}Ita_i + \beta_{13}{*}Swe_i + \\ & \beta_{14}{*}Fin_i + \varepsilon_i \end{aligned}$$

* The analysis implies the estimation of two models, as it uses two different dependent variables framed by the concept of innovative performance, namely, the efficiency of the innovation process (**Effi**) and the generation of technological innovations (**Tech_inn**).

Regarding the construction of the variables, the set of dependent variables (**Inn_perf**) is based on the questions of the survey asking about how well collaboration with external partners in innovation activities had performed against several objectives over the precedent three years. The scale of response indicates the extent of the agreement with the statements, from 1 ‘not at all’ to 7 ‘to a great extent’.

The set of items used corresponds to two different aspects of innovative performance, namely, efficiency and generation of technological innovation. Regarding the measure of the

[2] For more details on the project, see Manzini et al. (2013).

variable **Effi**, the questionnaire inquires about the following items: (a) reducing innovation risks, (b) reducing new product/process development costs and (c) reducing time to market. A variable was generated by means of factor analysis technique in order to obtain a linear combination of these three items. The coefficients of the synthetic variable were obtained by the regression scoring method (Thomson, 1951) [3]. Table 1 shows that the exploratory factor analysis extracted one single factor from the items, representing the entirety of the variance. It also displays the factor loadings and the scoring coefficients resulting from the analysis.

**Table 1**. Factor loadings and scoring coefficients for Efficiency

| | **Factor 1** | |
|---|---|---|
| | Factor loadings | Scoring coeff. |
| **Items** | | |
| Reducing risks | 0.7070 | 0.28432 |
| Reducing costs | 0.7985 | 0.43914 |
| Reducing times | 0.7091 | 0.28663 |
| | | |
| Eigenvalue | 1.64045 | |
| % Variance explained | 100.00 | |

As for the variable **Tech_inn**, respondents are asked whether they have successfully introduced (a) new or significantly improved products or services; and (b) new or significantly improved process of producing their products or services, which account for the fact of having or not obtained product and process innovations, respectively. The third edition of the Oslo Manual (OECD and Eurostat, 2005) defines product innovation as the introduction of a new (or significantly improved) good or service, that newness being related to the characteristics or the use of the product; and process innovation as the introduction of a new (or significantly improved) production or delivery method. Thus, the items account for the introduction of successful product and process innovations, which, also according to the Oslo Manual, constitute a comprehensive categorization of technological innovations. As for the previous construct, the variable was

[3] Same applies for all subsequent techniques for estimating scoring coefficients for synthetic variables in this work.

generated using a factor analysis technique, which resulted in the same factor loading for the two items (see Table 2).

**Table 2**. Factor loadings and scoring coefficients for Technological Innovation

| | Factor 1 | |
|---|---|---|
| | Factor loadings | Scoring coeff. |
| **Items** | | |
| Product innovations | 0.6501 | 0.42037 |
| Process innovations | 0.6501 | 0.42037 |
| | | |
| Eigenvalue | 0.84537 | |
| % Variance explained | 100.00 | |

Regarding technological proximity, the survey asks the respondents to indicate their agreement with several statements related to their firm's partners. The fourth item of the question, which reads '*partners' technological competences match up*', is used to construct the variable **Tech_prox**. The scale of the response ranges from 1 'strongly disagree' to 7 'strongly agree'. A quadratic term for this variable was also included, with purposes of testing the existence of an inverted U-shape relationship.

The variables related to the intensity of collaboration in the different stages of the innovative process were constructed based on the survey question about the extent to which the firms had collaborated with external partners in the different phases of the innovation process over the previous five years. The question contains four different items to assess the extent of the agreement with the statement, from 1 'not at all' to 7 'to a great extent', accounting for the phases of 'idea generation', 'experimentation', 'engineering' and'manufacturing'. In order to reduce these dimensions, an exploratory factor analysis was conducted, and two factors were retained. The factor loadings were obtained after an orthogonal varimax rotation (Kaiser, 1958).

**Table 3**. Factor loadings and scoring coefficients for Intensity of collaboration

| | Factor 1 | | Factor 2 | |
|---|---|---|---|---|
| | Factor loadings | Scoring coeff. | Factor loadings | Scoring coeff. |
| **Items** | | | | |

| | | | | |
|---|---|---|---|---|
| Idea generation | **0.6344** | **0.36598** | 0.1574 | -0.02119 |
| Experimentation | **0.6688** | **0.42275** | 0.1787 | -0.02128 |
| Engineering | 0.4037 | 0.12523 | **0.5576** | **0.41747** |
| Manufacturing | 0.0690 | -0.06950 | **0.5369** | **0.35946** |
| | | | | |
| Eigenvalue | 1.35100 | | 0.32236 | |
| % Variance explained | 80.74 | | 19.26 | |

As table 3 shows, the items related to the phases ‘idea generation’ and ‘experimentation’, strongly load on the first factor, while the items for engineering’ and ‘manufacturing’ strongly load on the second.

Also, the model includes the corresponding **multiplicative variables** (i.e., **Int_Phase1xTech_prox** and **Int_Phase2xTech_prox**), in order to capture the joint effect of technological proximity and collaboration intensity in the different phases.

A model containing just the precedent variables, which constitute the focus of the research, could imply the risk of attributing causal effects to a covariate that could in fact be due to some other aspects not introduced in the model but still affecting the independent variable while being related to the covariate of interest. Therefore, in order to avoid biases in the estimation of the coefficient of these covariates, the models include control variables measuring factors that scholarly practice traditionally understands as likely to have an impact on innovative performance and also as related to firms’ behavior towards innovation activities. For instance, the study introduces a measure for the innovativeness of the firm (**Innovat**), which collects the responses to the survey question ‘*we prioritize new product and service development and innovation to meet new and changing consumer demands*’, ranging from 1 ‘strongly disagree’ to 7 ‘strongly agree’. It is reasonable to expect that firms cultivating a strong innovation culture would perform better in terms of innovative outcomes, independently of their engagement in collaborative innovation practices; also, those firms would likely be prone to engage in such practices.

An indicator of the externalization of the firm (**Extern**) was also included. It corresponds to an item of the survey questioning about the number of different countries in which the company operates with a proprietary branch, ranging from 0 (if the firm operates in just one country) to 12 (it operates in 13 or more), and is thus a measure of the internationalization of the firm. A high scoring in this variable would be related to other successful activities, such as those related to innovation practices. Therefore, it is included in the analysis as a control variable.

Finally, dummy variables were introduced in order to control for the effect of firm size, the technology intensity of the industry sector, and the country where the firm is sited, all them well know aspects traditionally linked to innovative practices and outcomes.

The detail of the variables used for the estimation linear regression can be consulted in table 4.

**Table 4.** Indicators used in the quantitative analysis

| Variable | Label | Description |
|---|---|---|
| **DEPENDENT VARIABLE** | | |
| Efficiency | Effi | Synthetic variable referring to how well the firm has performed in the last three years in terms of reducing risks, costs and development times in the innovation process. |
| Technological innovations | Tech_inn | Synthetic variable referring to how well the firm has performed in the last three years in terms of introducing successful product and/or process innovations. |
| **INDEPENDENT VARIABLES** | | |
| Technological proximity | Tech_prox | It captures the degree of the technological proximity between the firm and its collaboration partners. |
| Technological proximity (quadratic) | $Tech\_prox^2$ | Quadratic term. |
| Collaboration intensity in early phases | Int_Phase1 | Synthetic variable capturing the extent to which the firm has collaborated with external partners the early phases of the innovation process over the last 5 years. |
| Collaboration intensity in late phases | Int_Phase2 | Synthetic variable capturing the extent to which the firm has collaborated with external partners in the late phases of the innovation process over the last 5 years. |
| Collaboration intensity in phase 1x Technological proximity | Int_Phase1xTech_prox | Multiplicative variable. |
| Collaboration intensity in phase 2x Technological proximity | Int_Phase2xTech_prox | Multiplicative variable. |
| Innovativeness (control variable) | Innovat | It captures whether the firm sports a innovation culture. |
| Externalization (control variable) | Extern | It captures the number of different countries in which the company operates with a proprietary branch. |

| | | |
|---|---|---|
| Firm size (control variable) | Size_small | Dummy |
| | Size_med | Dummy |
| Firm sector (control variable) | Sector_lowtech | Dummy |
| Country: Italy (control variable) | Ita | Dummy |
| Country: Sweden (control variable) | Swe | Dummy |
| Country: Finland (control variable) | Fin | Dummy |

## 4. RESULTS AND DISCUSSION

The following table shows descriptive statistics and the pairwise correlation coefficients (including significance level) of the variables in the model.

**Table 5.** Descriptive statistics, correlations and VIFs

| Variables | Obs. | Mean | St. D. | Pairwise correlations | | | | | | | | | | | | | VIF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
| 1. Effi | 463 | $8.66e^{-10}$ | 0.87 | 1 | | | | | | | | | | | | | - |
| 2. Tech_inn | 463 | $-4.49e^{-09}$ | 0.74 | 0.57 *** | 1 | | | | | | | | | | | | - |
| 3. Tech_prox | 463 | 4.54 | 1.41 | 0.35 *** | 0.30 *** | 1 | | | | | | | | | | | 1.14 |
| 4. Int_Phase1 | 467 | $-7.84e^{-10}$ | 0.75 | 0.29 *** | 0.30 *** | 0.19 *** | 1 | | | | | | | | | | 1.22 |
| 5. Int_Phase2 | 467 | $2.15e^{-10}$ | 0.65 | 0.24 *** | 0.28 *** | 0.34 *** | 0.15 ** | 1 | | | | | | | | | 1.21 |
| 6. Innovat | 467 | 5.40 | 1.52 | 0.30 *** | 0.34 *** | 0.20 *** | 0.11 * | 0.26 *** | 1 | | | | | | | | 1.12 |
| 7. Extern | 458 | 2.94 | 3.56 | 0.01 | -0.02 | 0.04 | 0.01 | 0.07 | 0.08 ^ | 1 | | | | | | | 1.70 |
| 8. Size_small | 467 | 0.43 | - | -0.09 * | -0.06 | -0.09 * | -0.05 | -0.04 | -0.06 | -0.41 *** | 1 | | | | | | 2.68 |
| 9. Size_med | 467 | 0.25 | - | 0.04 | -0.03 | 0.03 | 0.00 | 0.04 | 0.07 | -0.08 | -0.50 *** | 1 | | | | | 2.09 |
| 10. Sector_lowtech | 467 | 0.36 | - | 0.02 | 0.11 * | 0.04 | -0.06 | -0.02 | 0.01 | -0.04 | -0.04 | 0.05 | 1 | | | | 1.05 |
| 11. Ita | 467 | 0.32 | - | -0.00 | 0.20 *** | 0.08 ^ | -0.02 | 0.05 | 0.04 | -0.29 *** | 0.19 *** | -0.01 | 0.08 ^ | 1 | | | 4.03 |
| 12. Swe | 467 | 0.38 | - | 0.01 | -0.13 ** | -0.07 | 0.06 | 0.09 ^ | -0.06 | 0.26 *** | 0.06 | 0.06 | -0.15 *** | -0.54 *** | 1 | | 4.39 |
| 13. Fin | 467 | 0.18 | - | -0.08 | -0.14 *** | 0.01 | -0.15 ** | -0.16 *** | 0.01 | -0.03 | -0.06 | 0.10 * | 0.13 ** | -0.33 *** | -0.37 *** | 1 | 3.13 |

^ $p<0.1$; * $p<0.05$; ** $p<0.01$; *** $p<0.001$

Correlation values among independent variables are generally low to moderate suggesting low multicollinearity risks. The highest correlation between two pairs of explicative variables is 0.54 (in absolute terms, and between the country dummies for Italy and Sweden), far less than the problematic level of 0.75 (Tsui et al., 1995). This is confirmed by the analysis of the variance of inflation factors (VIF): the maximum VIF value is 4.38 (for the country dummy for Sweden), below the rule of thumb cut-off of 10, which again indicates that there are no serious multicollinearity problems in the models (Neter et al., 1996).

Turning now to the analysis of the causal effects, table 6 shows the estimations for the linear regression, displayed as hierarchical models adding covariates progressively, from a model with only the control variables (model 1) as predictors to the complete model proposed above (model 4). As it can be seen, $R^2$ measure reflects an increase of the explicative capacity of the hierarchical model when progressing in the introduction of variables up until the configuration of model 4 (the F-test of overall significance confirms that the indicator is statistically significant in all cases). This is generally also true for the adjusted $R^2$ measure, which takes into account the number of predictors incorporated to the model, and is thus a better indicator to assess the explanatory capacity of models that containing different numbers of covariates. This is also consistent with the Wald tests performed in order to test the joint significance of the newly added variables in each model. In this sense, the only case for which the progression in the hierarchy does not yield a better performance of the model is model 3 for the dependent variable Tech_Inn; thus challenging the significance of the introduction of the quadratic term of technological proximity, an aspect which will be further commented on below.

**Table 6.** Results for the estimation of the hierarchical models

| | **Model 1** | **Model 2** | **Model 3** | **Model 4** |
|---|---|---|---|---|
| **DEPENDENT VARIABLE #1**<br>Effi | | | | |
| **INDEPENDENT VARIALES** | | | | |
| Tech_prox | | 0.16*** | -0.11 | -0.12 |
| $Tech\_prox^2$ | | | 0.03* | 0.03* |
| Int_Phase1 | | 0.19*** | 0.18** | -0.08 |

| | | | | |
|---|---|---|---|---|
| Int_Phase2 | | 0.15* | 0.15* | 0.58** |
| Int_Phase1xTech_prox | | | | 0.06 |
| Int_Phase2xTech_prox | | | | -0.09* |
| Innovat | 0.18*** | 0.12*** | 0.12*** | 0.12*** |
| Extern | -0.02 | -0.02 | -0.02 | -0.02 |
| Size_small | -0.17 | -0.09 | -0.11 | -0.11 |
| Size_med | -0.03 | 0.01 | -0.02 | -0.04 |
| Sector_lowtech | 0.04 | 0.05 | 0.04 | 0.05 |
| Ita | -0.21 | -0.26 | -0.24 | -0.21 |
| Swe | -0.11 | -0.15 | -0.14 | -0.09 |
| Fin | -0.34^ | -0.24 | -0.22 | -0.18 |
| Constant | -0.66** | -1.08*** | -0.59^ | -0.60^ |

| | | | | |
|---|---|---|---|---|
| $R^2$ | 0.1133 | 0.2346 | 0.2421 | 0.2511 |
| Adjusted $R^2$ | 0.0975 | 0.2157 | 0.2216 | 0.2274 |
| F-test (overal significance) [4] | 4.17*** | 12.43*** | 11.84*** | 10.61*** |
| F-test (Wald test) [5] | | 23.55*** | 4.40* | 2.67^ |

**DEPENDENT VARIABLE #2**

Tech_inn

**INDEPENDENT VARIALES**

| | | | | |
|---|---|---|---|---|
| Tech_prox | | 0.09*** | 0.02 | 0.01 |
| Tech_prox$^2$ | | | 0.01 | 0.01 |
| Int_Phase1 | | 0.13** | 0.13** | -0.11 |
| Int_Phase2 | | 0.20*** | 0.20*** | 0.54*** |
| Int_Phase1xTech_prox | | | | 0.05^ |
| Int_Phase2xTech_prox | | | | -0.07* |
| Innovat | 0.16*** | 0.12*** | 0.12*** | 0.12*** |
| Extern | -0.01 | -0.01 | -0.01 | -0.01 |
| Size_small | -0.22* | -0.16 | -0.17 | -0.17 |
| Size_med | -0.21* | -0.19^ | -0.19^ | -0.21 |
| Sector_lowtech | 0.16* | 0.17** | 0.17** | 0.17** |
| Ita | 0.12 | 0.12 | 0.13 | 0.15 |
| Swe | -0.11 | -0.12 | -0.12 | -0.07 |
| Fin | -0.30* | -0.20 | -0.19 | -0.15 |
| Constant | -0.69*** | -0.94*** | -0.80** | -0.82** |

| | | | | |
|---|---|---|---|---|
| $R^2$ | 0.1871 | 0.2894 | 0.2902 | 0.2990 |
| Adjusted $R^2$ | 0.1726 | 0.2718 | 0.2710 | 0.2768 |
| F-test | 12.92*** | 16.51*** | 15.16*** | 13.50*** |
| F-test (Wald test) | | 21.40*** | 0.51 | 2.78^ |

^ p<0.1; * p <0.05; ** p <0.01; *** p<0.001

[4] The F test performed tests for the overall significance of the model, providing the implicit null hypothesis that the fit of the intercept-only model and the estimated model are equal, thus indicating whether the $R^2$ measure is statistically significant.

[5] The Wald test performed shows whether the newly introduced variables in the model (with respect to precedent model) are simultaneously equal to zero or if that null hypothesis can be rejected.

The calculation of the beta coefficients and their significance is complemented with the calculation of average marginal effects (AMEs) on the two measures of innovative performance. As the models in this work involve multiplicative terms, the estimated regression coefficients cannot be read as the predicted change the dependent variable due to a unit change in the covariate of interest; thus, the interpretation of the relationship between the dependent and the independent variables benefits from the display of AMEs (Leeper, 2017). While scholars generally recognize that the analysis of the results yielded by non linear models calls for the calculation of indicators beyond the estimated coefficients of the covariates, because these do not communicate the unconditional average effects, this awareness should arise also in the case of linear interaction regressions; in this sense, indicators such as the aforementioned AMEs provide relevant information to perform accurate and meaningful interpretations of the causal relationships in the linear models (Brambor et al., 2006).

The AMEs displayed in the following figures are obtained from the complete estimated model (model 4) and with confidence intervals of %95.

**Figure 2**. AMEs of the three independent variables of interest

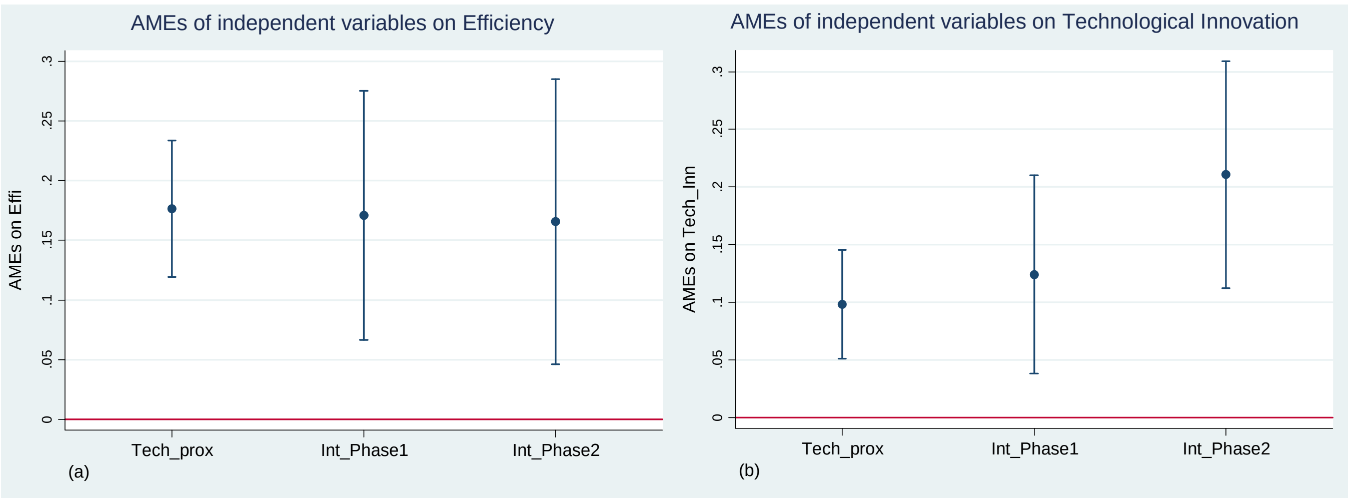
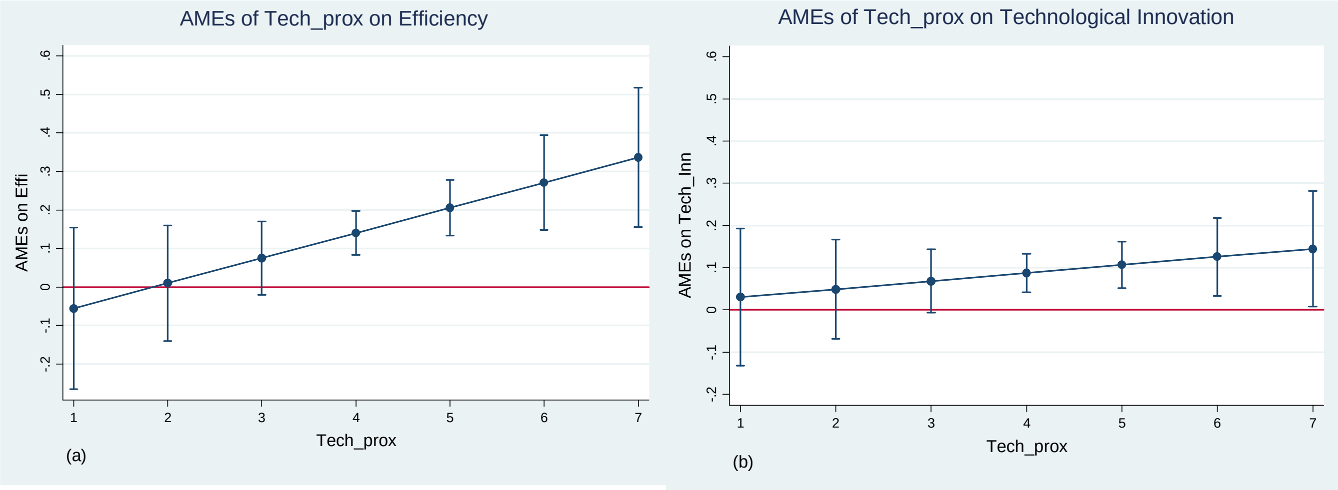


**Figure 3**. AMEs of technological proximity along its rage of values




Figures 2a and 2b show the average unconditional effect of all three independent variables (technological proximity and intensity of collaboration in the two phases), while figures 3a and 3b display the AMEs of technological proximity along its own range of values. Regarding the specific relationship between technological proximity and innovative performance, both the beta coefficient estimated (see results for models 3 and 4) and the AMEs of the variable for different values of its range show no evidence of the existence of an inverted U-shape with none of the measures of performance. The relationship between technological proximity and the generation of technological innovation seems to be merely linear. On the one hand, while the estimated coefficient of technological proximity is positive and significant in model 2, nor the variable 'Tech_prox' nor the quadratic term show significant estimated betas in models 3 and 4. On the other hand, although the AMEs show increasing punctual estimations along the range of values of the variable, the estimated intervals do not seem to support the existence of significant differences among them, thus leading to conclude that those AMEs are in fact of the same magnitude. As commented above, this observations are consistent with the measures of the goodness of fits and the results of the Wald test. As for the effects on efficiency, results somehow suggest a positive curvilinear relationship, with a significant coefficient for the quadratic term of technological proximity in models 3 and 4 (and non-significant for the variable 'Tech_prox'), and increasing positive AMEs along the range of values of the variable. In any case, both for efficiency and for the generation of technological innovations, the findings do no support the existence of a saturation point from which more technological proximity with R&D partners leads to worse innovative performance. This leads to **the rejection of hypothesis 1**.

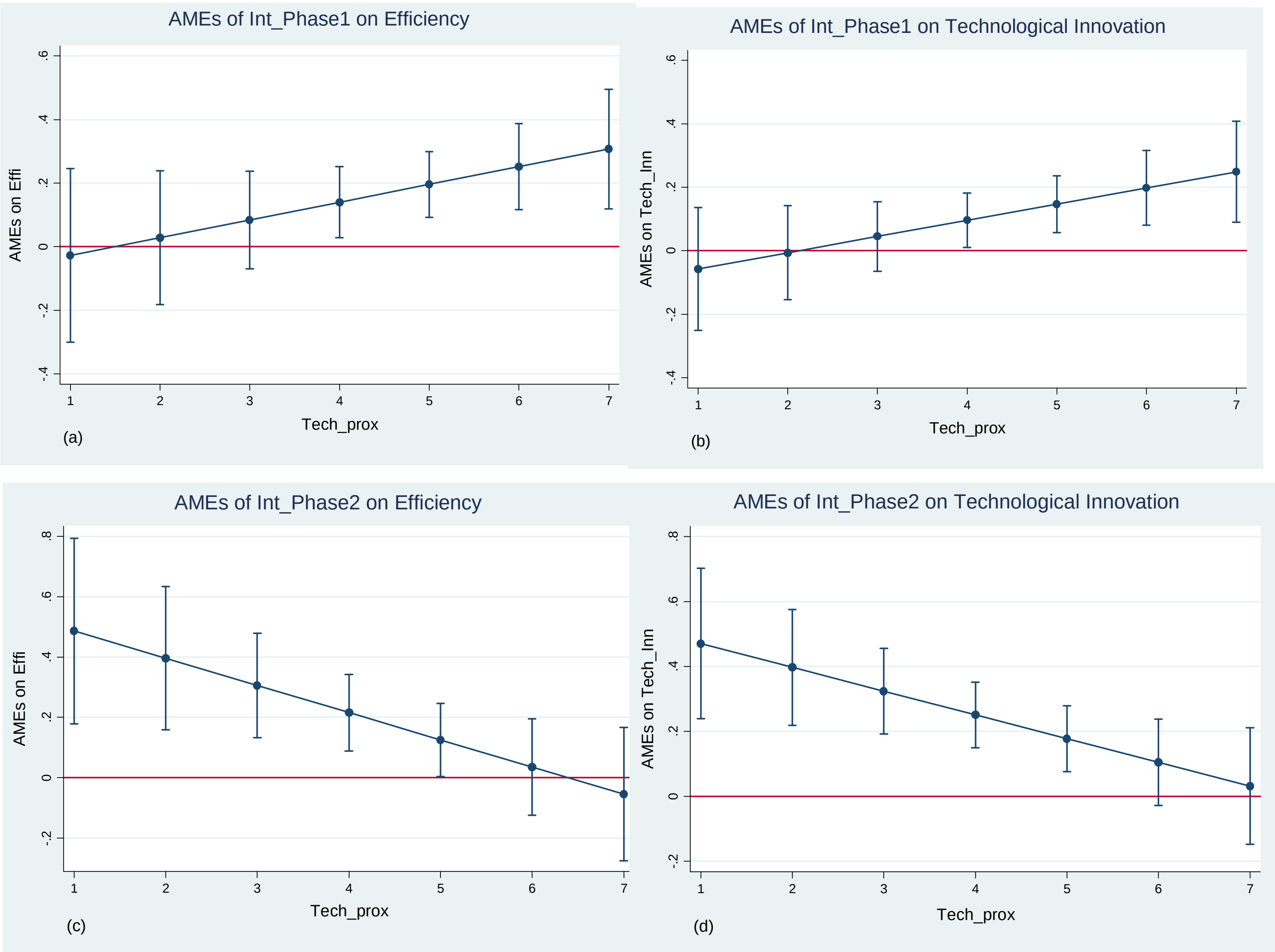
As commented in the theoretical framework of this work, a low level of knowledge overlap between partners implies greater challenges for identifying, acquiring and assimilating that distant knowledge (Parida et al., 2016). Indeed, when pursuing to profit from collaborative innovation practices, there is a need to understand the source's knowledge base, which in turn requires a certain technological proximity to it. In this sense, Perez and Soete (1988) claimed that there is a minimum level of shared knowledge under which firms are not capable of bridging their technological gap, and Boschma and Lambooy (1999) concluded that a firm's own knowledge base should be close enough to the new knowledge in order to understand and process it successfully.

According to the evidence found here, there is a positive relationship between technological proximity and innovative performance, in line with the theoretical arguments based on relative absorptive capacity. However, it challenges the rationale of the 'proximity paradox' (Boschma and Frenken, 2010), feeds the polemic around this notion and provides new insight to propose new approaches to this phenomenon.

Turning now to the effect of the intensity of collaboration in the early and late phases of the innovation funnel, figures 2a and 2b clearly show that it is positive and significant both for the efficiency of the process and for the generation of technological innovations. The coefficients of the corresponding covariates in models 2 and 3, being also positive and significant, support this conclusion, even though the coefficients of 'Int_Phase1' lose their significance when the multiplicative terms are introduced in model 4, and aspect that will be addressed below. Thus **baseline hypothesis 2 is confirmed**, providing further support to the theories claiming that, in order to transfer tacit knowledge and develop complex tasks, as it is common in R&D partnerships, firms need to commit to the project and engage intensely in the relationship with the external sources of innovation (Berchichi, 2011; Hsieh and Tidd, 2012). These findings lead to a similar conclusion as that posited for technological proximity; that is, the more intense the relationship with the collaborators of the R&D partnerships, the better in terms of innovative performance. A refinement of such conclusion regarding whether it is sustained for partnerships portfolios diverging in terms of type and number of partners would be undoubtedly valuable. This would provide further understanding on the benefits of collaborating intensely with R&D external sources; i.e., determining whether firms should commit to deep relationships with a wide range of partners or if they should focus on collaborating intensely with key and preferred partners, as stated by Berchichi (2011).

Figures 4a and 4b provide the graphic representation for interpreting the joint effect of technological proximity and the intensity of collaboration in the early phase of the innovation process. In both cases, the AMEs of the intensity of collaboration increase along the range of values of technological proximity. The estimated coefficients of the multiplicative covariate give valuable information too; in the odel 4 for the effect on efficiency, such coefficient is non-significant, while in the model for the effect on the generation of technological innovations, it is positive and significant. These findings imply **some evidence to support hypothesis 3a**, showing the existence of a certain complementarity between technological proximity and the intensity of collaboration in the early phase. Also, the graphical depiction and the estimated coefficients of the covariate 'Int_Phase1' in model 4 (non-significant for both measures of performance) hint that firms need a certain level of technological proximity in order to profit from collaborating intensely with their innovation partners. This idea is consistent with literature stressing that overlapping technological bases enable the transfer and recombination knowledge and help in managing complex interactions, which are indeed characteristics of the early stages of the collaborative innovation process (e.g., Srikanth and Puranam, 2011; Lakemond et al., 2016).

**Figure 4**. AMEs of the Intensity of collaboration in the early and late phases, depending on the values of technological proximity




The findings for the joint effect of technological proximity and collaboration intensity in the later stages of the innovation process are more conclusive. Figures 4c and 4d, portraying the AMEs of the intensity of collaboration in the late phase for different values of technological proximity, show that the higher the matchup between the firms' technological base and their partners, the lower the positive effect of collaborating intensively. This holds for both measures of innovative performance. Also, the estimated coefficients of the interactive covariate are both negative and significant. Therefore, the results of this work point to a substitution effect between technological proximity and the intensity of collaboration in the late phase and, thus, fully **support hypothesis 3b**: collaborating very intensely in the later stages of the innovation process with very close partners, in terms of technological bases, is detrimental for innovative performance. An explanation for this phenomenon would be, as commented above, that involuntary spillovers and collaborators' opportunistic behavior are more likely to arise in the late phase of the innovative process and, also, if those collaborators are proximate in technological terms (Lakemond et al., 2016; Boschma and Frenken; 2010). As a consequence, appropriability problems would affect firms' willingness to fully engage and contribute to the project, which would in turn negatively affect the outcomes of this project (Ritala Hurmelinna-Laukkanen, 2013).

Finally, it is worth offering some comments on the estimated coefficients of the control variables. As it can be seen in table 6, only innovativeness and technological sector have a significant effect on performance, the latter only for the generation of technological innovations (not for efficiency) and of a sign contrary to the one expected: the coefficient implies a positive influence of the firms of low technological sectors with respect to firms of high technological industries. This signals potential interesting further research dealing with the questions of this work applied to a study distinguishing clusters according to the technological sector.

## 5. CONCLUSIONS

The work has focused on understanding how technological proximity and the intensity of collaboration along the innovation funnel influence the outcomes of collaborative innovation process, in terms of efficiency and generation of technological innovations. In particular, it aimed to determine the nature of the relationship between the aforementioned variables and innovative performance regarding the following aspects: what is the unconditional effect of technological proximity on performance?; what is the unconditional effect of the intensity of collaboration in different phases of the process on performance?; and, what is the joint effect of technological proximity and collaboration along the innovation funnel on performance?

In order to answer these questions, regression models were estimated over a dataset with more than 400 firms from different European countries (i.e., Italy, Sweden, Finland and UK), and results were interpreted analyzing both the estimated coefficients and the AMEs of the covariates of the models.

This analysis led to the following conclusions. Regarding the first question, results showed that technological proximity has a positive relationship with innovative performance. This finding was somehow contradictory with the expectations of the study, whose theoretical framework relies heavily on the notion of ‘proximity paradox’ (Boschma and Frenken, 2010) and thus predicted an inverted U-shape relationship. The evidence found here, however, excluded the existence of a saturation level of proximity from which the positive effects on performance would start to diminish.

On the other hand, findings on the effects of collaboration intensity matched the predictions of the theoretical framework; i.e., collaborating intensely with the partners of the innovation projects, no matter the stage of the funnel, is beneficial both in terms of efficiency and of generation of technological innovations.

Results on the joint effect of technological proximity and the intensity of collaboration were interpreted as follows. In the early stage, there is some evidence to sustain that there is a certain complementarity between the two variables and that firms indeed need to have a certain level of technological overlap with their innovation partners in order to benefit from collaborating intensely with them. However, in the later stages of the innovation process, collaborating very intensely with very technologically close partners proves to be detrimental for innovative performance, thus pointing to a substitution effect between technological proximity and the intensity of collaboration. Involuntary spillovers due to closeness and collaborators’ opportunistic behavior, which are more likely to arise in the late phase of the innovative process, would explain this negative joint effect and warn about potential appropriability problems.

The analysis of the findings of this research is valuable to practitioners, policy makers and, in general, agents involved with innovation management, as it provides relevant recommendations regarding collaborative innovation practices. In general terms, evidence was found to suggest that firms should try to collaborate intensely with technologically related partners. Also, depending of the phase of innovation funnel in which the collaboration takes place, recommendations vary. In the earlier stages of the process, choosing partners with proximate technological bases with whom to collaborate intensely might not only be beneficial due to the unconditional effects of proximity and intensity, but it could also imply the enhancing of the positive effects of both aspects on the generation of product and process innovations. Moreover, in order to profit from intense collaborations in this early phase, firms should pursue a certain level of technological proximity with their innovation partners. On the other hand, when collaborating in the later stages of the innovation process, firms shouldpay attention to proper protection mechanisms, in order to avoid the detrimental effects of collaborating intensely with technologically proximate partners.

This research also adds to innovation management literature by providing interesting contributions, as it delves into the phenomenon of proximity and tries to unravel how non-geographical proximity (which is said to be disregarded compared to geographical proximity) is relevant for innovation outcomes, bringing surprising evidence to the debate around the ‘proximity paradox’, which is still led by inconclusive results. In fact, the evidence found here suggest that technological proximity with innovation partners is always desirable, and that there is no saturation point from which this proximity starts positing problems.

Besides, the study takes into account the collaborative innovation practices as a process and provides insight on how innovative performance might be affected by complementarities betweeen technological proximity and the intensity of collaboration along the different phases of the innovation funnel.

The findings of this work provide further contribution to the academic community by suggesting some interesting lines for future research. First, the evidence found here is challenging for the notion of the ‘proximity paradox’ and provides interesting insight regarding the polemic; Indeed, it might be interesting to determine whether firms that benefit from ever growing levels of technological proximity with their partners are still able to obtain related yet complementary knowledge from such partners. That is, whether in situations of high technological relatedness, there is still room to benefit from the existence of complementary resources through the combination of internal and external sources of innovation, an aspect which has been signaled as one of the main foundations for the success of collaborative innovation practices (e.g., Stieglitz and Heine, 2007). After all, the foundation of the resource-based view is precisely that firms perform differently and that these differences are due to the resource heterogeneity they possess (Penrose, 1959). These considerations would constitute a valuable basis for future research: i.e., is there really no saturation point for technological proximity?, does that mean that firms are never 'too close' in technological terms?; would that imply that firms do in fact benefit from R&D partnerships just because these ventures perform better in terms of efficiency or are firms so unique that even a high technological matchup leaves room for heterogeneity?

Second, the substitution effect found between technological proximity and the intensity of collaboration in the later phases of the innovation process suggest that there is still room for research on the appropriability problems related to the R&D partnerships. This problem has been studied in scientific literature; however, further research is needed regarding the relationship of collaborative innovation practices and appropriability with performance (Laursen and Salter, 2014; Stefan and Bengtsson, 2017) and with proximity. More specifically, and in line with the findings for this work, such research would benefit from taking into consideration the use of appropriation mechanisms in different stages of the collaborative innovation process (Zobel et al., 2017). That is, research on proximity would benefit from introducing a perspective on appropriability, linking the effects of technological with the use of protection mechanisms in the different stages of the collaborative innovation process.

Finally, results hinted that considering different clusters according to the technological sector might refine the conclusions of this study.

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